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by Ronald J. Wilson and James M. McKay

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OF THE XB-70-1 AIRPLANE

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SUMMARY

Data are presented on landing-contact conditions for the first 48 landings of the XB-70-1 airplane. Landing weights varied from 419,800 pounds (190,400 kilograms) to 274,600 pounds (124,600 kilograms). Vertical velocities at touchdown ranged from 5.26 feet/second (1.603 meters/second) to 1.49 feet/second (0.454 meter/second). Maximum indicated airspeed was 195.0 knots, with a minimum of 167.3 knots.

Landing-contact conditions of the XB-70-1 are compared with those of a modern turbojet transport. The mean vertical velocity at touchdown for the XB-70-1 was 3.21 feet/second (0.978 meter/second), which was 1.59 feet/second (0.484 meter/second) higher than that reported for the turbojet transport. A mean indicated airspeed of 180.5 knots was 47.7 knots greater than that reported for the transport. The maximum XB-70-1 roll angle (3.0°) and rolling velocity (3.28 deg/sec) at touchdown were less than the values (4.3° and 8.7 deg/sec, respectively) for the transport.

The measured main-gear maximum vertical reaction generally compared favorably with predicted values. The nose-gear initial maximum vertical reactions were generally less than the predicted values.

The mean acceleration measured at the pilot's station was 1.39g due to main-gear impact and 1.54g due to nose-gear impact. The mean accelerations experienced at the center of gravity due to main-gear and nose-gear impact were 1.37g and 1.23g, respectively.

INTRODUCTION

Future supersonic-cruise vehicles of large volume and weight operating in the Mach 3 region will require design criteria different from those of the subsonic aircraft of today. The design criteria for these supersonic-cruise vehicles will probably result in lifting surfaces with low aspect ratios for flight at high speeds, a fuselage with a high slenderness ratio, and low ratios of empty to gross weight. Such criteria will, in turn, result in large, flexible structures with low structural frequencies and associated increases in the amplitude of motion of specific stations, such as the landing-gear attach points and the crew and passenger stations.

Consequently, the landing-gear system of large supersonic aircraft will be required to meet a higher range of loads than those of more rigid airplanes. A higher range of operating temperatures, combined with taxiing and landing under extreme conditions of weight, will also impose additional requirements on the landing-gear system.

Because the XB-70 is the first large supersonic-cruise vehicle with performance, flexibility, and inertial characteristics representative of future designs, a landing loads study was made on the airplane. The purpose of this program was to measure landing-contact conditions as well as representative gear loads due to landing impact and the resulting accelerations imparted to the airframe, and to compare these data with the results of similar investigations of the landing-contact conditions of turbojet aircraft now in service.

No special techniques, speeds, or other restrictions were specified for this study, nor were any flights made solely to obtain landing data. The glide slope for landing was approximately 1.5°, in contrast to a normal instrument landing system approach of 2.5° to 3.0°. The XB-70 pilots were frequently assisted by callouts from escort pilots that indicated height above the runway before touchdown.

This paper presents data obtained from the first 48 landings of the XB-70-1 airplane. Included are main-gear and nose-gear landing loads, accelerations of the aircraft structure due to landing impact, and initial landing-contact conditions. Data are from flight measurements obtained by North American Aviation, Inc., and the NASA Flight Research Center at Edwards, Calif.

DESCRIPTION OF THE AIRPLANE

The XB-70-1 airplane (fig. 1) is described in detail in reference 1. Briefly, the airplane has a design gross weight in excess of 500,000 pounds (226,800 kilograms)

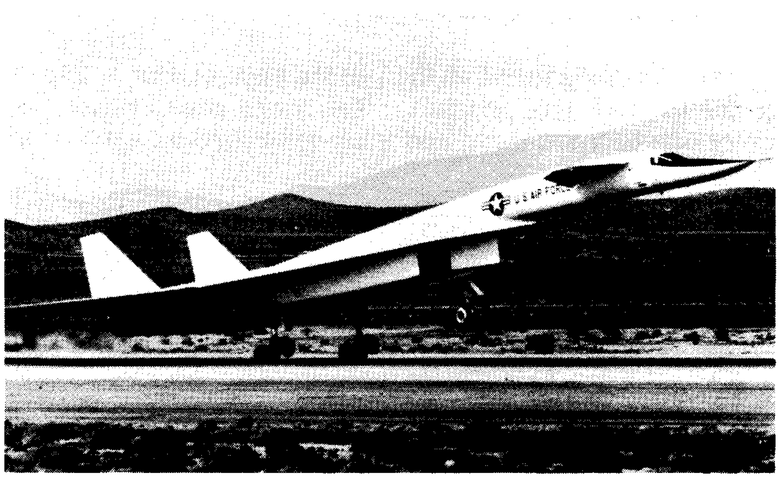

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Figure 1.— XB-70-1 airplane.

and a design cruise speed of Mach 3 at 70,000 feet (21,300 meters) to 80,000 feet (24,400 meters) altitude. It has a thin, low-aspect-ratio delta wing with folding tips and a 65.6° swept leading edge, twin all-movable vertical stabilizers, elevon surfaces for pitch and roll control, and a movable canard with trailing-edge flaps. The flight control system is irreversible.

Propulsion is provided by six YJ93-GE-3 engines. Each engine is in the 30,000-pound (13,608-kilogram) thrust class with full afterburner at sea level. The six engines are mounted side by side at the rear of the fuselage in a single nacelle under the center section of the wing. The nacelle is divided into twin, two-dimensional, mixed-compression inlets that incorporate variable-throat wall positions and adjustable bypass airflow doors for optimum operation throughout the Mach number range.

LANDING-GEAR SYSTEM

The XB-70 landing-gear system provides braking, directional control, and vertical-displacement damping during ground operations, shock absorption during landing, and deceleration after landing or for takeoff rejection. The system, after a thermal exposure induced by a Mach 3 environment, must support and distribute the following maximum dynamic and static loads: 25,000 foot-pounds (33,900 newton-meters) static steering torque; 542,000 pounds (245,800 kilograms) taxi weight; 42,000,000 foot-pounds/second (56,944,400 watts) braking energy absorption rate (during takeoff rejection); and 296,000 foot-pounds (401,300 newton-meters) landing shock absorption.

The conventional tricycle landing gear on the XB-70 was selected for its inherent stability, light weight, and compatibility with the airplane configuration. Each main gear (fig. 2) incorporates a bogie beam that provides mounting for four tires and wheel assemblies, two brake assemblies, a brake reference wheel, and a shock strut. Each two-wheel assembly of the forward and aft bogie sections is corotating.

The tires are 40 × 17.5 - 18, type VIII, with a 36-ply rating. For protection from the flight heat environment, a heat-resistant material is impregnated throughout the body of the tires with a silver-colored material painted on the exterior surface. During flight, the wheel-well walls of the airplane are held to a nominal 250° F (394° K) by a circulating ethylene-glycol solution from the environmental control system.

The brake assembly on the bogie beam has a brake stack of 21 stationary and 20 revolving discs between the pair of wheels at each end. The stationary discs are splined on a stationary ring cage, and the rotating discs are splined to the torque tube to which the wheels are attached. The wheels run on bearings fitted directly to the forged H-11 alloy steel bogie instead of an axle. Because the brake discs are separated from the wheels, much more efficient cooling is achieved.

An automatic antiskid system, with separate sensing wheels, is designed to provide maximum braking efficiency under all runway conditions. In the system, a small fifth wheel on each bogie rotates a small electronic sensor. The fifth wheel measures the true ground speed of the aircraft with no slippage and transmits this information to the brake computer. One of the main wheels also has a speed sensor which in turn transmits its speed to the brake computer. The difference between the two outputs is the amount of slippage. The amount of load on the wheels is measured and transmitted to the computer by a torque sensor, thus enabling the computer to determine the ground friction coefficient. When slippage is greater than 15 percent, the computer compares the rate of slippage and the ground friction coefficient and predicts the skid point. The brake pressure is then relieved. The tire of the fifth wheel is 14 × 4.5 - 8, with a 4-ply rating, of thin-wall construction.

The struts are of the air-oil type, pressurized with nitrogen, and with internal metering features that provide complementary shock-absorbing characteristics for required taxiing and landing loads. The total main-gear stroke is 13 3/4 inches (0.349 meter) with a static compressed deflection of 2 inches (0.051 meter).

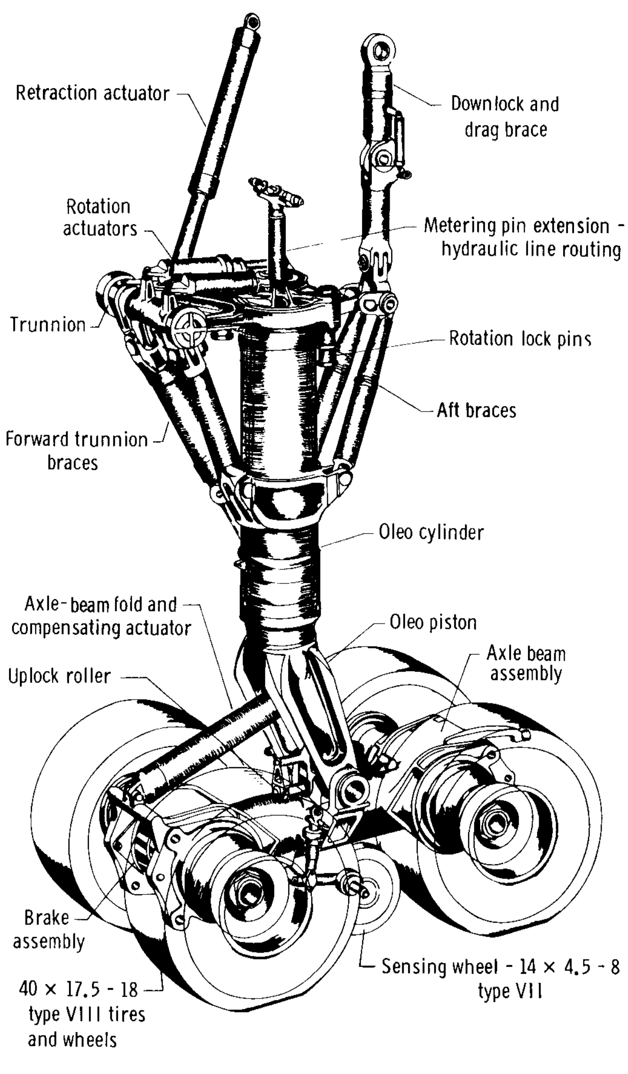


Figure 2.– Main landing gear.

The main leg of the gear is attached to the fuselage by a trunnion. No torque links are used, since the torque is transmitted to the upper structure splines inside the main-gear leg.

The axle-beam fold and compensating actuator connected between the oleo piston and the forward end of the bogie assembly performs three functions: it folds and extends the bogies; it delays contact of the forward pair of wheels on landing, thus attenuating the vertical impact and spin-up loads; and it compensates for the difference in vertical ground load between the front and rear axles due to operation of the anti-skid brake system.

The nose landing gear (fig. 3) consists of dual corotating wheels and is steerable. The shock strut is of the oleopneumatic type with a maximum stroke of 14 1/4 inches (0.362 meter) and a static-to-compressed deflection of 3 inches (0.076 meter). The gear is steerable on the ground through an angle of ±58°. Similar to the main-gear system, the nose gear is fabricated largely of H-11 alloy steel, and the tires are 40 × 17.5 - 18, type VIII, with thermal protection.

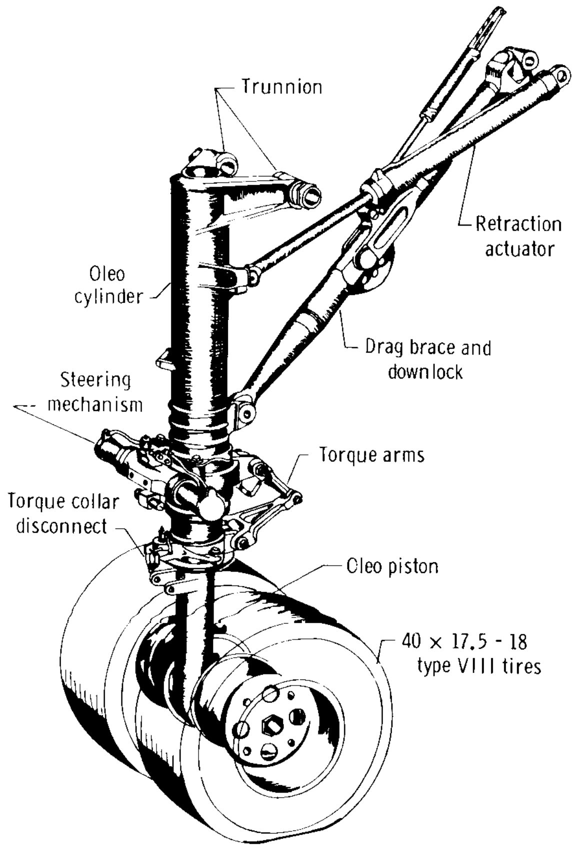


Figure 3.— Nose landing gear.

INSTRUMENTATION AND DATA REDUCTION

Pertinent parameters for this investigation were recorded on the XB-70-1 internal recording system. The parameters are listed in table I in conjunction with the type of pickup, range of measurement, frequency response, type of recording, accuracy, and location. Figure 4 shows the approximate locations of the XB-70-1 instrumentation.

Instruments installed in environmentally controlled areas were calibrated at ambient temperatures. In locations where in-flight elevated temperatures were anticipated, calibrations were made at a sufficient number of temperature conditions to enable the error due to temperature changes to be determined. Temperature corrections were not required for landing-loads instrumentation.

Data were recorded on magnetic tape. Either a digital or an analog technique was used, depending upon the nature of the particular parameter to be recorded and its frequency-response characteristics. The digital recordings consisted

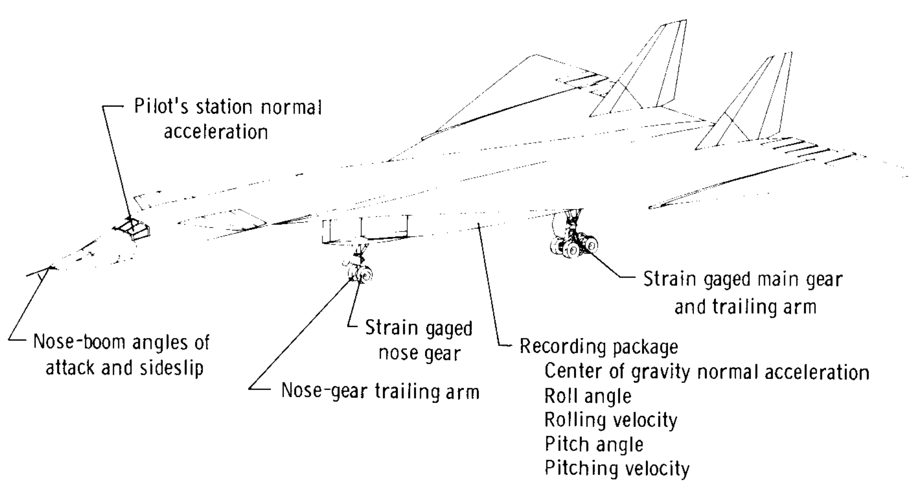


Figure 4.— Instrumentation location.

of static or quasi-static data when frequency-response requirements were low. Each parameter was sequentially sampled and recorded on magnetic tape in 10-bit parallel binary form. The channel capacity of the recording equipment was 706 parameters. Recording time was 90 minutes, with a tape packing density of 666 data words per linear inch of tape.

The airborne digital-data tape was reduced by first editing to select the desired parameters and time periods for analysis. The time-edited data were converted from the flight-recorded format to engineering units, and calibrations were applied. The data were then tabulated or plotted as required. All data reduction was done with automatic data-processing equipment.

Analog recordings on magnetic tape followed standard IRIG frequency-modulation techniques. To match the output of the data sensors, millivolt-type subcarrier oscillators were used. The oscillators were connected in groups of 12 to each tape track, thereby providing a maximum channel capacity of 144 data parameters. A magnetic-tape speed of 15 inches/second (0.381 meter/second) was used, which provided a recording time of 90 minutes and a frequency-response variation per parameter per track from 11 cycles/second to 450 cycles/second. The overall error of data recorded on this tape equipment was approximately ±3 percent of full scale, including the transmission lead error.

The analog data were reduced by feeding the flight data into a playback tape transport which divided a single track into 12 signals. The 12 signals were then fed into a discriminator bank, the output of which could be digitized. The signals were corrected and scaled before being reproduced on the oscillograph recorders of a direct-writer recorder.

The XB-70-1 rate-of-sink instrumentation equipment consisted of electrical position transducers connected to mechanical probes mounted on all three gears. The probe mechanism (fig. 5) was a trailing arm that was free to rotate about a pivot point

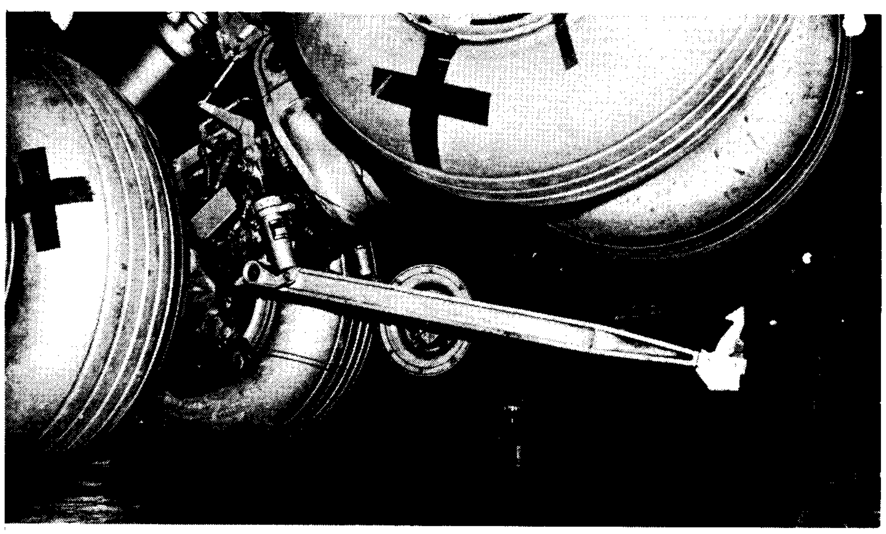
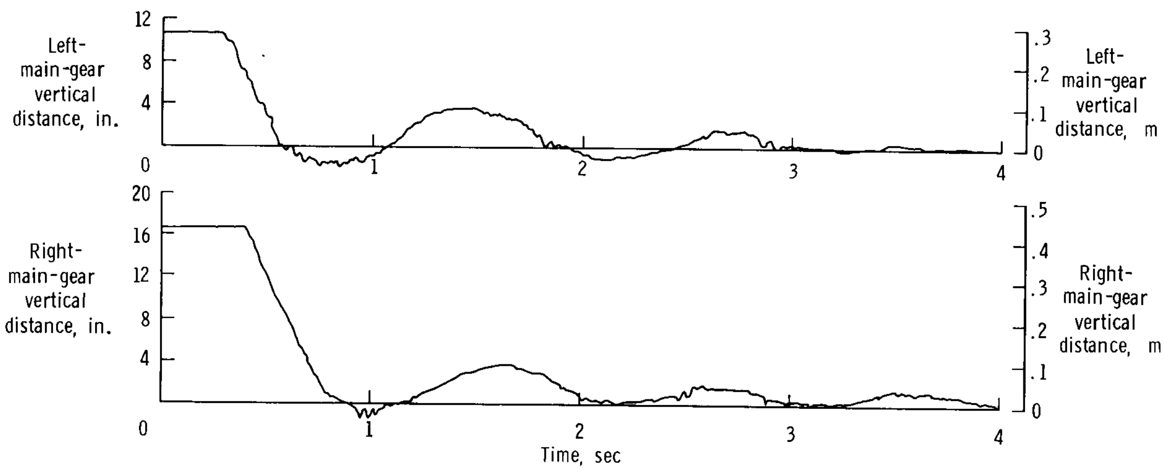
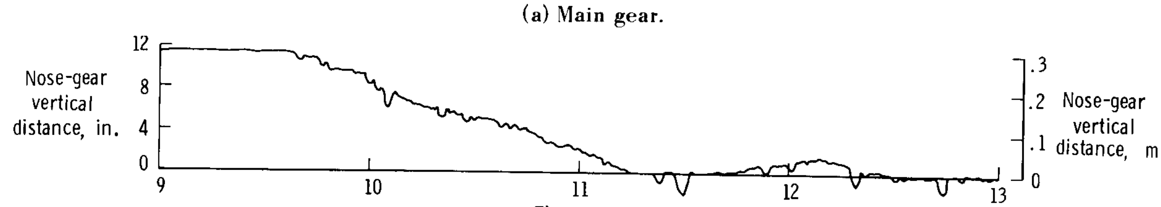


Figure 5.— Main-gear rate-of-sink arm.

on the lower extremity of each shock strut. In the landing position, the trailing arms were extended rearward and downward so that the ground-contact shoe was in a stationary position below the tires. At landing, the arms made initial contact with the ground and, as the airplane descended, the arm was forced to retract. The position transducer sensed the arm position, which was directly related to the height of the wheel from the ground, once the arm made contact. These data, when recorded as a function of time (figs. 6(a) and 6(b)), resulted in an accurate measurement of vertical velocity of the nose gear and the aft truck of each main gear at touchdown.



(a) Main gear.



(b) Nose gear.

Figure 6.– Typical time history of trailing arm vertical distance for vertical-velocity measurement.

DISCUSSION OF RESULTS

The first 48 landings of the XB-70-1 airplane were made by four different pilots, all with considerable experience in flight research with large jet aircraft. Although the pilots were aware that landing data were being obtained, no special techniques, speeds, or other restrictions were requested, nor were any flights made solely to obtain landing data. Also, as an operational procedure, the XB-70 pilots were assisted by pilots in escort aircraft who called out height above the runway on most of the landings. Once enough piloting experience was obtained, the height callouts were not always required.

Landing-Contact Conditions

The landing-contact conditions for the first 48 landings of the XB-70-1 airplane are presented in table II. All the landings were made on a 15,000-foot (4,572-meter) concrete runway at Edwards Air Force Base, Calif., with the following exceptions: The landing of flight 4 took place on a 12,000-foot (3,658-meter) concrete runway at Palmdale, Calif. Flights 2 and 6 terminated on Rogers Dry Lake, Edwards, Calif., on runway 17, which is 7.5 miles (12 kilometers) long. Flights 12, 13, and 37 terminated on Rogers Dry Lake on runway 18, which is 4 miles (6.4 kilometers) long.

The trailing arms were installed after the fourth flight; the first vertical-velocity data obtained with these probes were recorded on the fifth landing. Vertical-velocity data were not obtained for the nose gear after flight 19 or for the main gear after flight 34 because of flight safety and instrumentation requirements. Other omissions in table II were caused by intermittent or total loss of instrumentation recording capability through system failures or emergency conditions.

Landing weights varied from 419,800 pounds (190,400 kilograms) on flight 9 to 274,600 pounds (124,600 kilograms) on flight 37. Vertical velocity ranged from 5.26 feet/second (1.603 meters/second) on flight 32 to 1.49 feet/second (0.454 meter/second) on flight 13. A vertical velocity of 1.01 feet/second (0.308 meter/second) was experienced on the left main gear on flight 7, 0.27 second after the right main gear touched down. However, on flight 13, the left main gear contacted 0.03 second after the right main gear. Because of the small time difference, the landing was considered to be symmetrical. A maximum indicated airspeed of 195.0 knots was experienced on flight 9 and a minimum of 167.3 knots on flight 4.

Landing-contact data from the first 48 landings of the XB-70-1 airplane are compared in the table on the following page with similar data from reference 2 for a modern turbojet transport. As shown in the table, the mean airspeed for the XB-70-1 of 180.5 knots was 47.7 knots greater than that reported for the turbojet. The landing of XB-70-1 flight 4 at Palmdale, Calif., with an indicated airspeed of 167.3 knots indicates that lower velocities can be obtained. As a matter of interest, velocities as low as 154.9 knots were obtained with the XB-70-2, as shown in reference 3.

The mean vertical velocity of the first wheel to contact at touchdown for the XB-70-1 was 3.21 feet/second (0.978 meter/second)[1], which was 1.59 feet/second (0.484 meter/second) higher than that reported for the turbojet. Also, the maximum angle of roll (3.0°) and rolling velocities (3.28 deg/sec) for the XB-70-1 at touchdown were less than those for the turbojet (4.3° and 8.7 deg/sec, respectively). This difference may be attributed to the high roll control of the XB-70-1 at low speeds. Greater roll rates were experienced during landing than shown in the table on page 9; the maximum value was 6.23 deg/sec on flight 3. However, the only flights used in the comparison of rolling velocities were those for which the time of touchdown of both gear could be determined.

Reference 3 includes additional information on XB-70 landing-contact conditions.

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[1] For this calculation of mean vertical velocity at touchdown, only those cases were considered where data were available for vertical velocity and time of touchdown for both gear; therefore, only 18 samples were available for calculation of mean value.

XB-70-1 AND TURBOJET LANDING-CONTACT CONDITIONS

		XB-70-1	Turbojet
Airspeed, knots	Maximum	195	159.9
	Mean	180.5	132.8
Vertical velocity, ft/sec (m/sec)	Maximum	5.26 (1.603)	4.2 (1.280)
	Mean	3.21 (.978)	1.62 (.494)
Angle of roll, deg	Maximum	3.00	4.3
	Mean	1.00	1.04
Rolling velocity toward first wheel to touch down, deg/sec	Maximum	3.28	4.4
	Mean	1.07	1.50
Rolling velocity away from first wheel to touch down, deg/sec	Maximum	3.22	8.7
	Mean	1.08	1.66

Landing-Impact Conditions

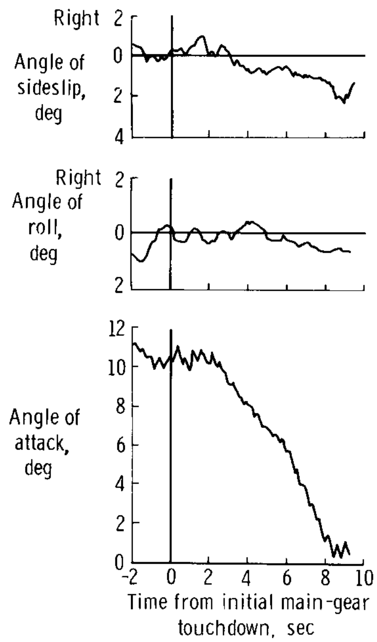
Quantities measured during XB-70-1 main-gear and nose-gear impact are summarized in table III. To present a more complete history of the landing-impact conditions, histories of three landings are shown in figures 7 to 9.

Figure 7 is a time history of flight 9 on which the highest gross weight at landing (419,800 lb (190,400 kg)) was recorded. Time zero indicates the time at which an aft main-gear truck made contact with the runway. The landing was symmetrical, with both main gear contacting the ground simultaneously. The right main gear touched the runway at a vertical velocity of 2.70 feet/second (0.823 meter/second). Indicated airspeed at touchdown was 195.0 knots, the highest velocity recorded.

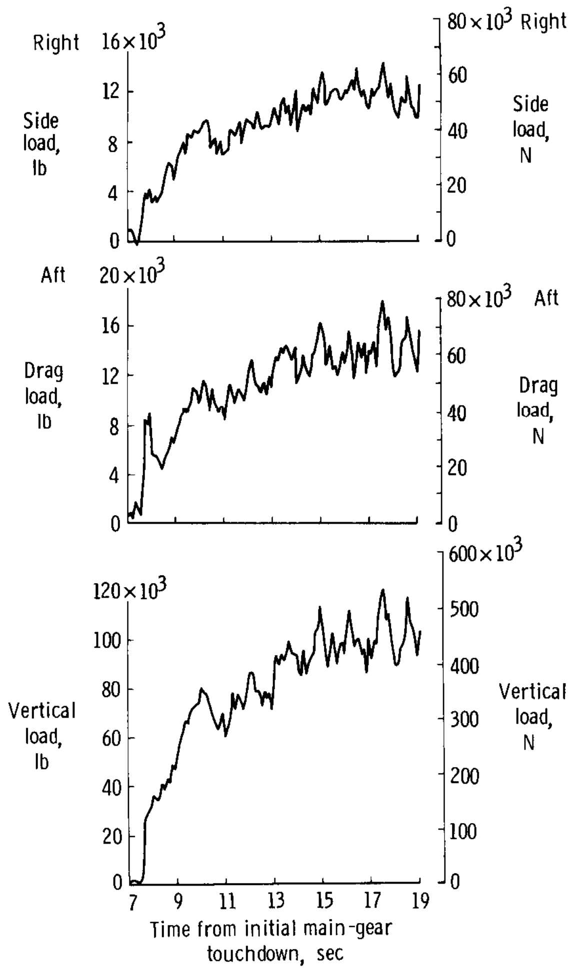
Figure 7(a) shows the airplane angles of attack, roll, and sideslip before and after initial impact. The main-gear loads for this flight could be only approximated because of instrumentation difficulties and, therefore, are not presented.

The nose-gear loads and accelerations are presented because of the interest in extreme landing conditions due to weight. The nose-gear vertical, drag, and side loads are presented in figure 7(b). The vertical velocity of the nose gear at impact was 1.59 feet/second (0.485 meter/second) approximately 7.5 seconds after main-gear touchdown. A rapid increase in the vertical load, along with the associated increase in drag load, was experienced during the spin-up period. The drag load reached a peak value during spin-up of approximately 8900 pounds (39,589 newtons), combined with a vertical load of 31,100 pounds (138,339 newtons). The vertical load then increased slowly toward its maximum value of 121,000 pounds (538,235 newtons) approximately 10 seconds after nose-gear touchdown.

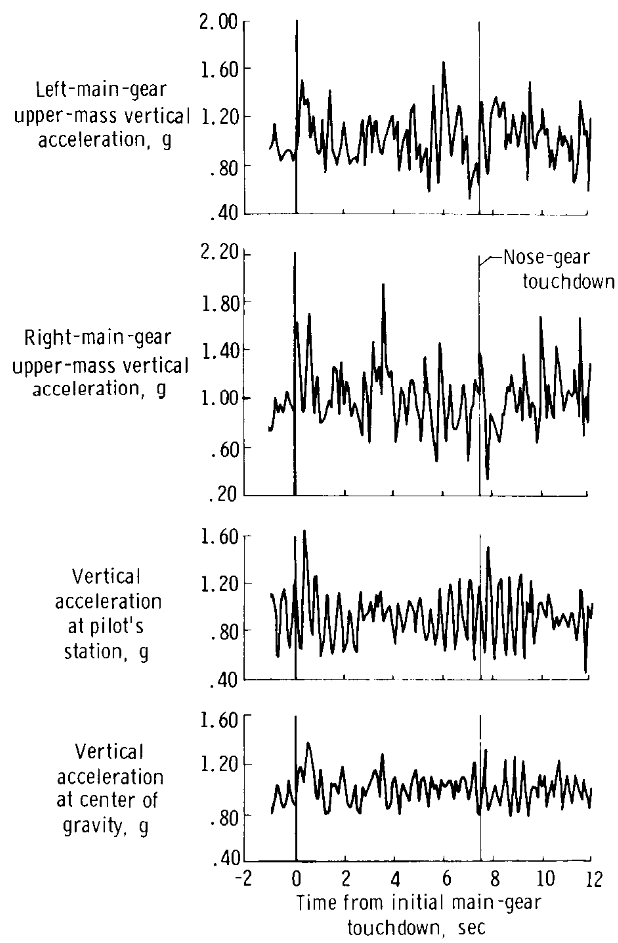
Vertical accelerations at the airplane center of gravity, pilot's station, and right- and left-main-gear upper mass are shown in figure 7(c). Peak vertical accelerations at the center of gravity and pilot's station during main-gear touchdown were 1.40g and 1.65g, respectively. During nose-gear impact the peak accelerations at the center of gravity and the pilot's station reached 1.34g and 1.51g, respectively.



(a) Airplane attitude.



(b) Nose-gear loads.

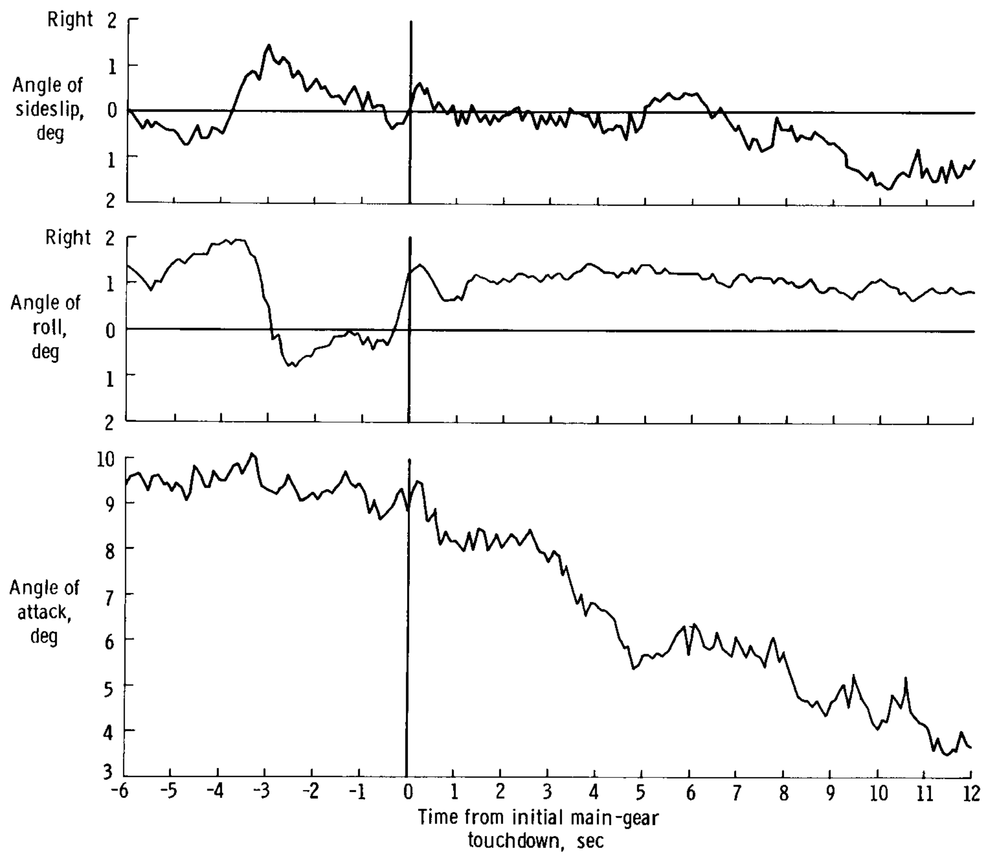


(c) Airplane and main-gear upper-mass accelerations.

Figure 7.– Typical time histories of angles of attack, roll, and sideslip, nose-gear loads, and accelerations. XB-70-1 flight 9.

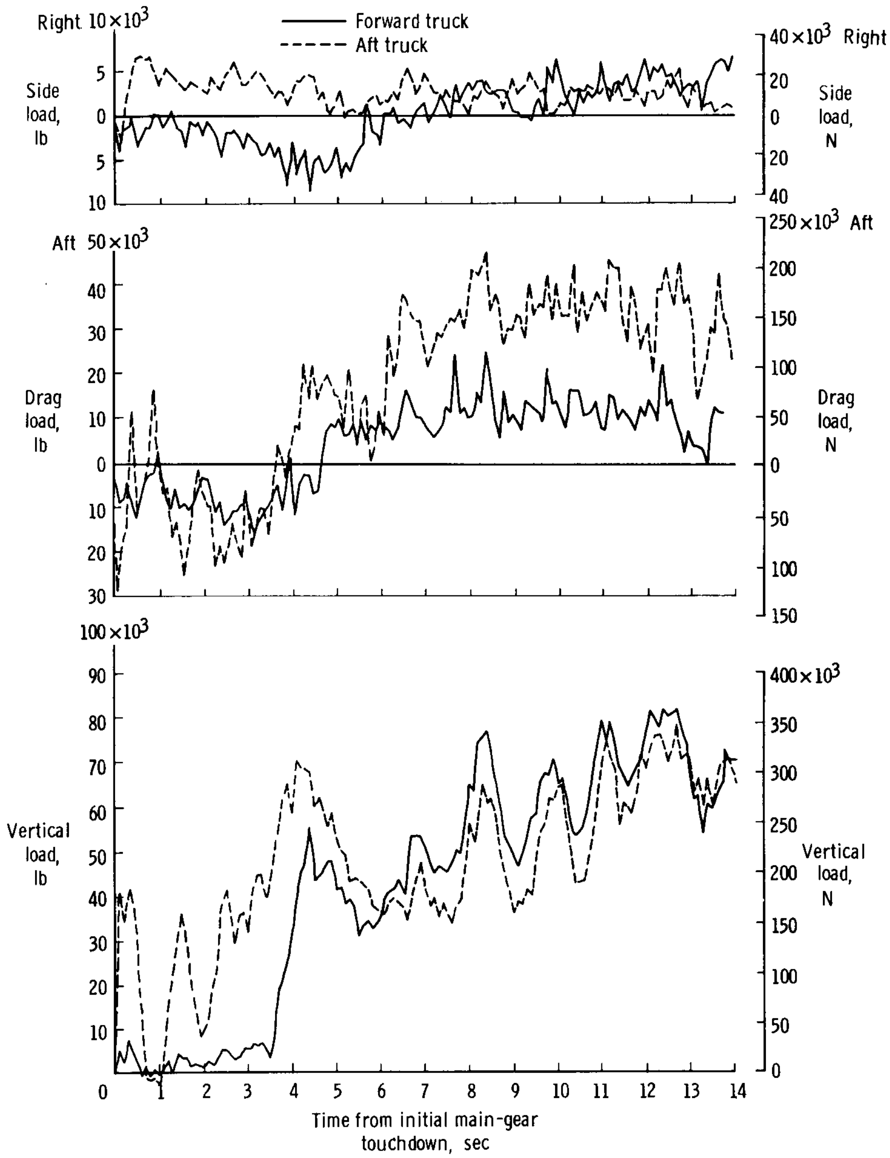
Figure 8 presents time histories of the landing of flight 5. The landing weight was 295,200 pounds (133,900 kilograms) and the indicated airspeed at touchdown, 179.5 knots. One of the highest vertical velocities of this investigation (4.17 feet/second (1.271 meters/second)) was attained during this landing at main-gear touchdown, with the right main gear touching down 0.01 second after the left main gear.

Figure 8(a) is a time history of the angles of attack, roll, and sideslip during landing. The vertical, drag, and side loads for the right-main-gear forward and aft truck are shown in figure 8(b). Figure 8(c) shows the total main-gear loads for the left and right main gear. The left main gear drag loads were not computed due to instrumentation difficulties. The initial total vertical load due to the impact and spin-up of the aft truck was 66,000 pounds (293,582 newtons) on the left main gear and 51,000 pounds (226,859 newtons) on the right main gear. As shown in figure 8(b), the right forward truck touched approximately 3.5 seconds after the initial touchdown. The total load reached a maximum near nose-gear touchdown at 12.7 seconds. The maximum vertical load (fig. 8(c)) was 158,000 pounds (702,819 newtons) for the left main gear and 163,000 pounds (725,060 newtons) for the right main gear. Maximum drag and side loads were 73,000 pounds (324,720 newtons) and 12,500 pounds (55,602 newtons), respectively.



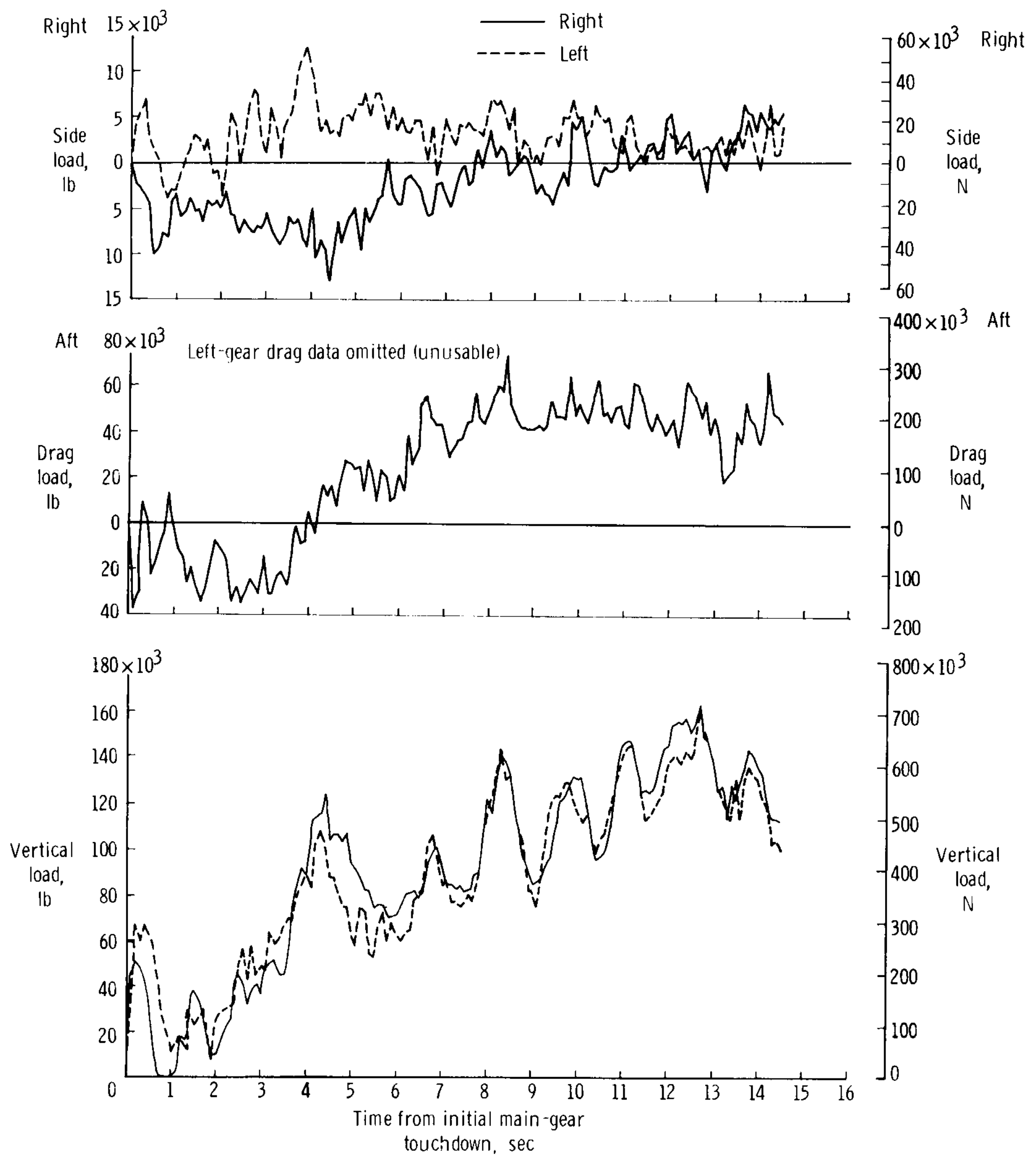
(a) Airplane attitude.

Figure 8.— Typical time histories of angles of attack, roll, and sideslip, landing-gear loads, and accelerations. XB-70-1 flight 5.



(b) Forward and aft right main-gear truck loads.

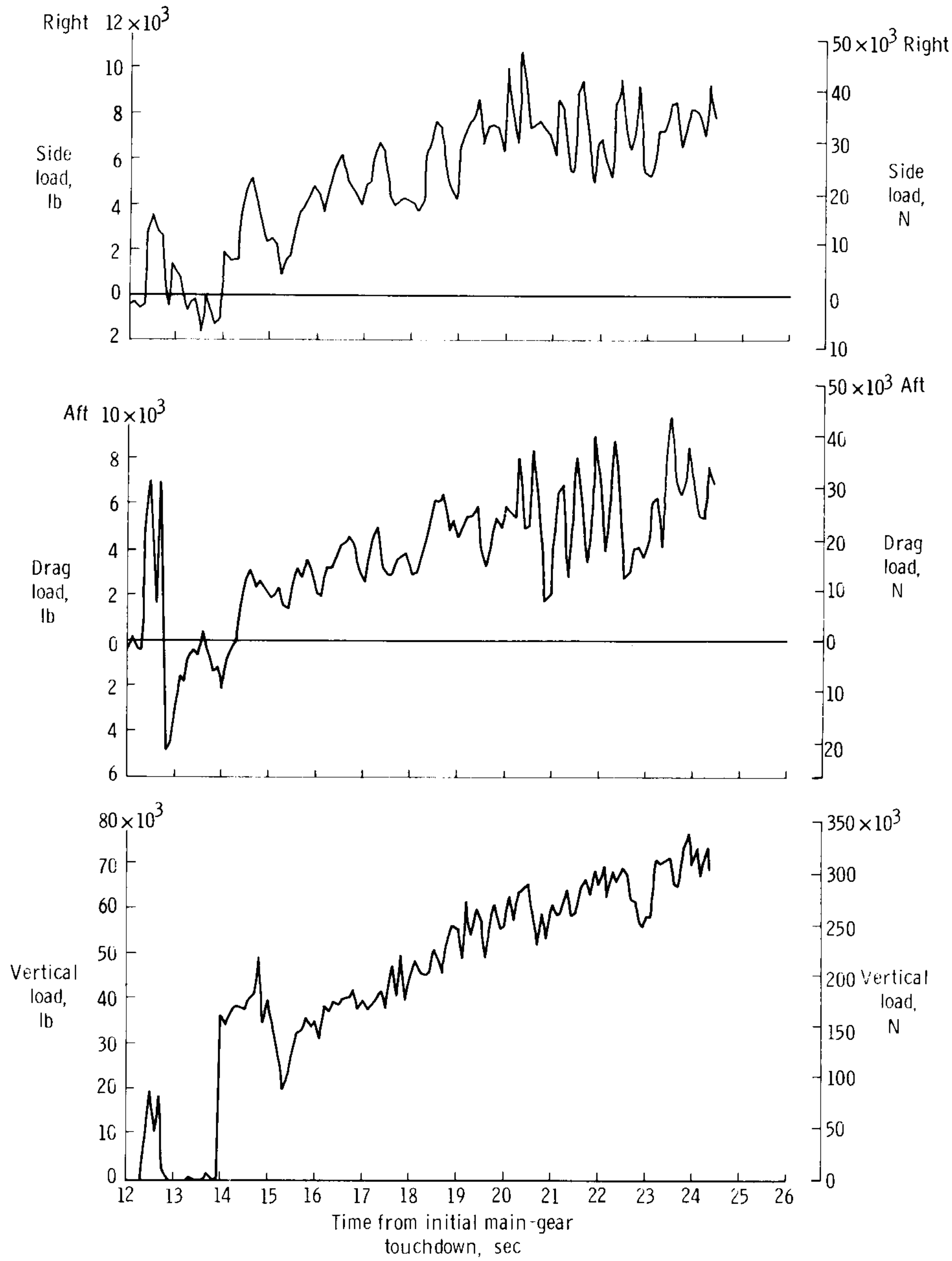
Figure 8.– Continued.



(c) Total main-gear loads.

Figure 8.— Continued.

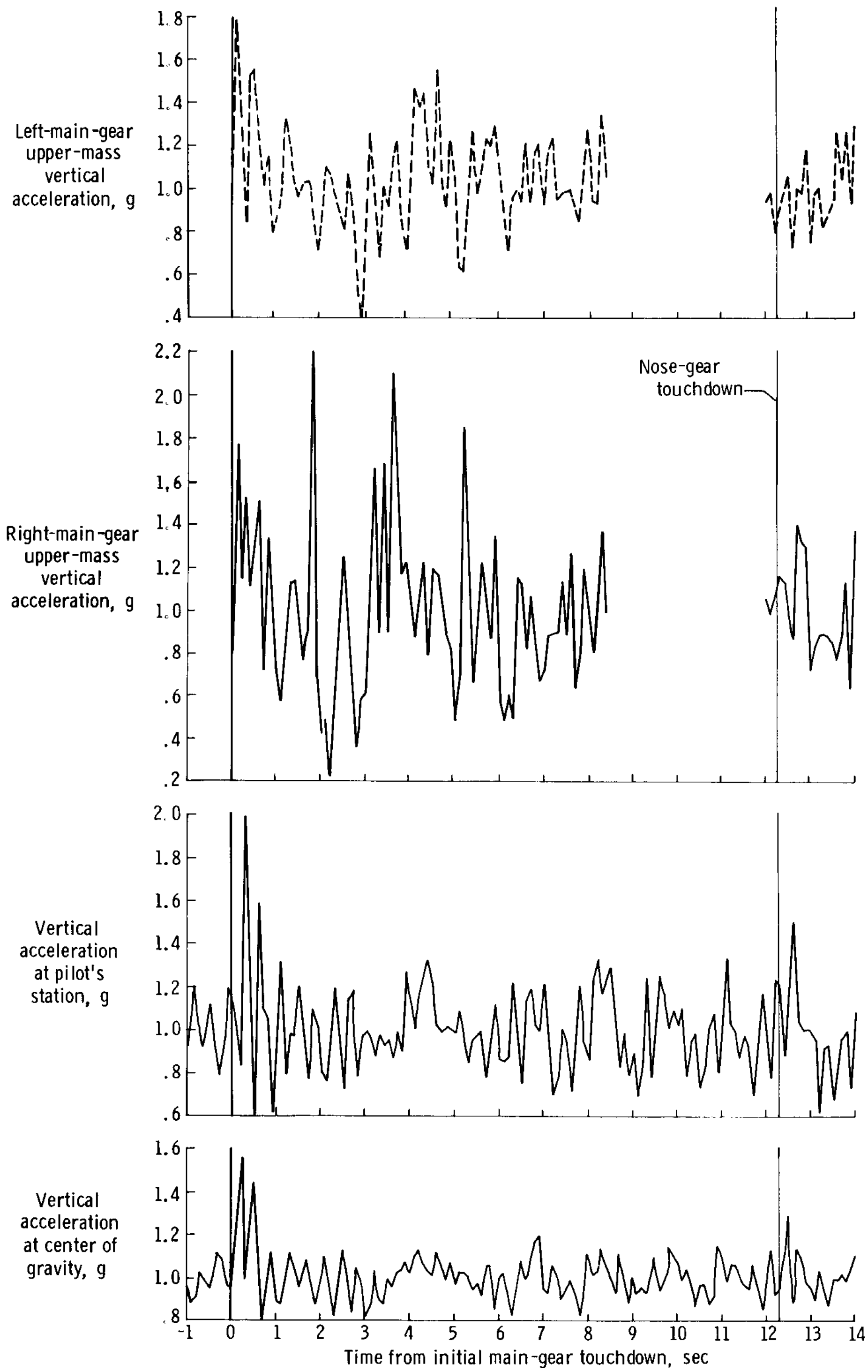
The nose-gear loads are presented in figure 8(d). Nose-gear touchdown occurred approximately 12.3 seconds after main-gear touchdown at a vertical velocity of 0.91 foot/second (0.277 meter/second). The nose gear bounced slightly then remained on the ground at 13.9 seconds. For the nose gear the maximum vertical load reached approximately 76,140 pounds (338,687 newtons); the maximum drag load, 9800 pounds (43,592 newtons); and the maximum side load, 10,400 pounds (46,261 newtons).



(d) Nose-gear loads.

Figure 8.– Continued.

Vertical accelerations due to landing impact are presented in figure 8(e). The peak vertical acceleration at the center of gravity and the pilot's station were 1.56g and 1.99g, respectively, at main-gear impact. At nose-gear impact the corresponding accelerations were 1.28g and 1.50g.

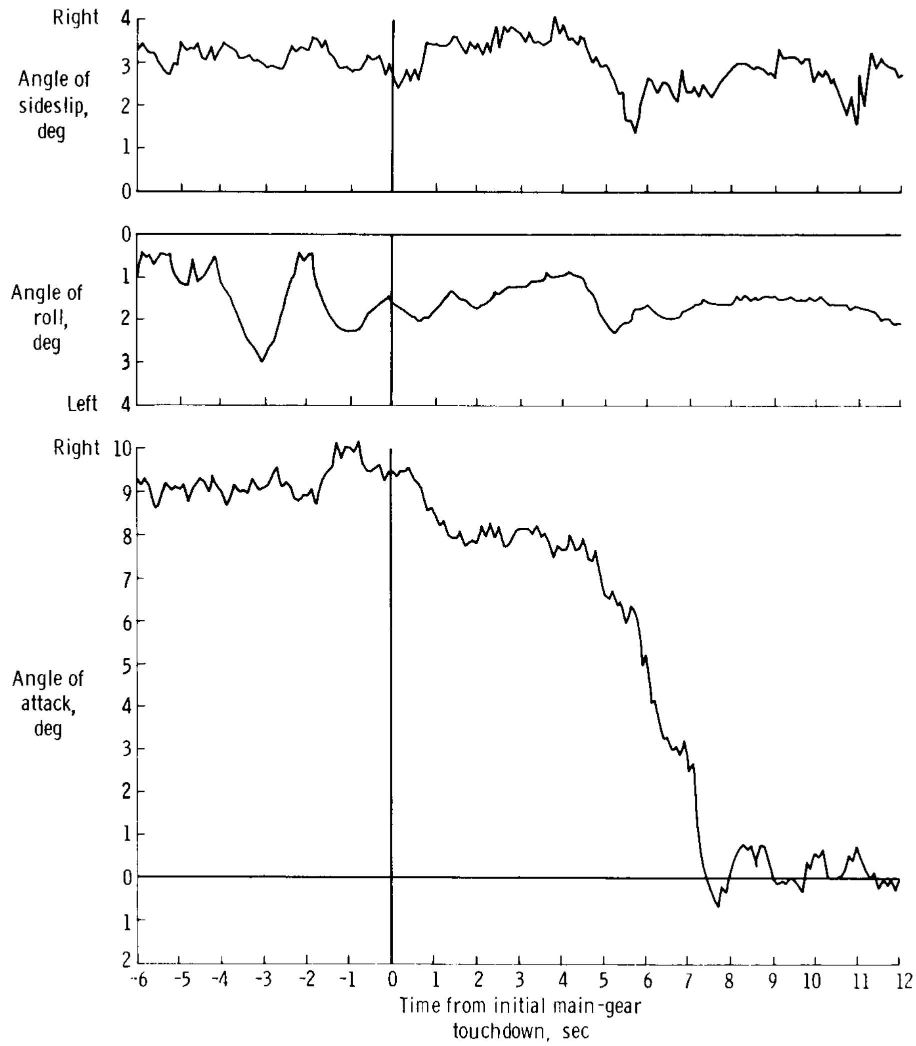


(e) Airplane and main-gear upper-mass accelerations.

Figure 8.— Concluded.

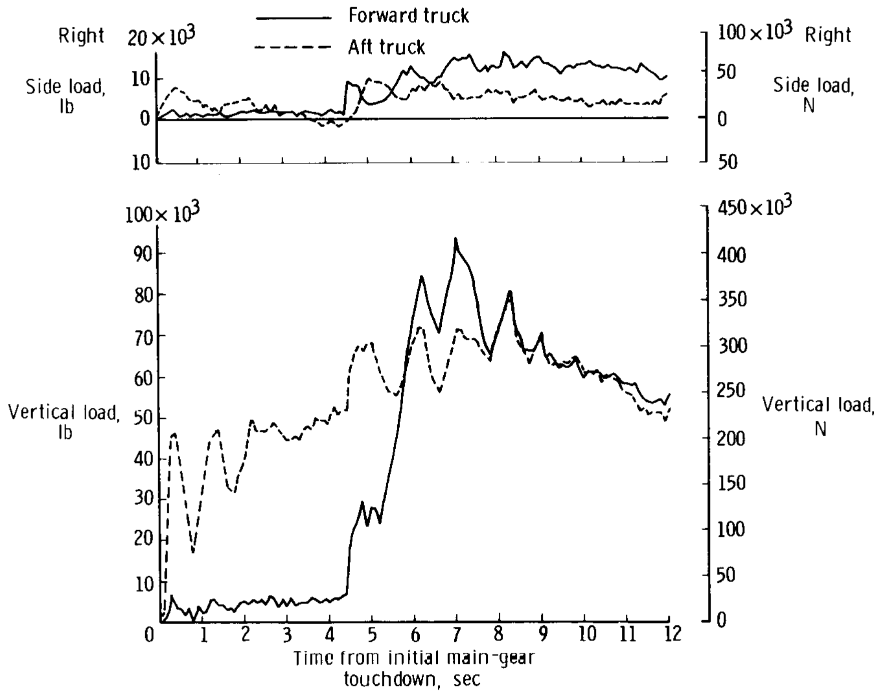
Figure 9 presents time histories of flight 13 which had a landing weight of 300,200 pounds (136,200 kilograms). Indicated airspeed at touchdown was 179.1 knots, with a vertical velocity of approximately 1.49 feet/second (0.454 meter/second). Of particular interest for this landing was a nose-gear vertical velocity of 2.35 feet/second (0.716 meter/second), the highest recorded nose-gear vertical velocity in this study.

The airplane angles of attack, roll, and sideslip for flight 13 are presented in figure 9(a). Main-gear loads are shown in figures 9(b) and 9(c). The main-gear drag loads were not computed because of instrumentation difficulties. The peak vertical load (fig. 9(c)) experienced by the main gear during spin-up of the aft truck was 47,500 pounds (211,290 newtons) for the left main gear and 53,400 pounds (237,534 newtons) for the right main gear. Approximately 4.4 seconds after contact of the aft truck, the forward truck made contact. The vertical load reached a maximum of 165,100 pounds (734,401 newtons) for the left main gear and 165,700 pounds (737,070 newtons) for the right main gear.

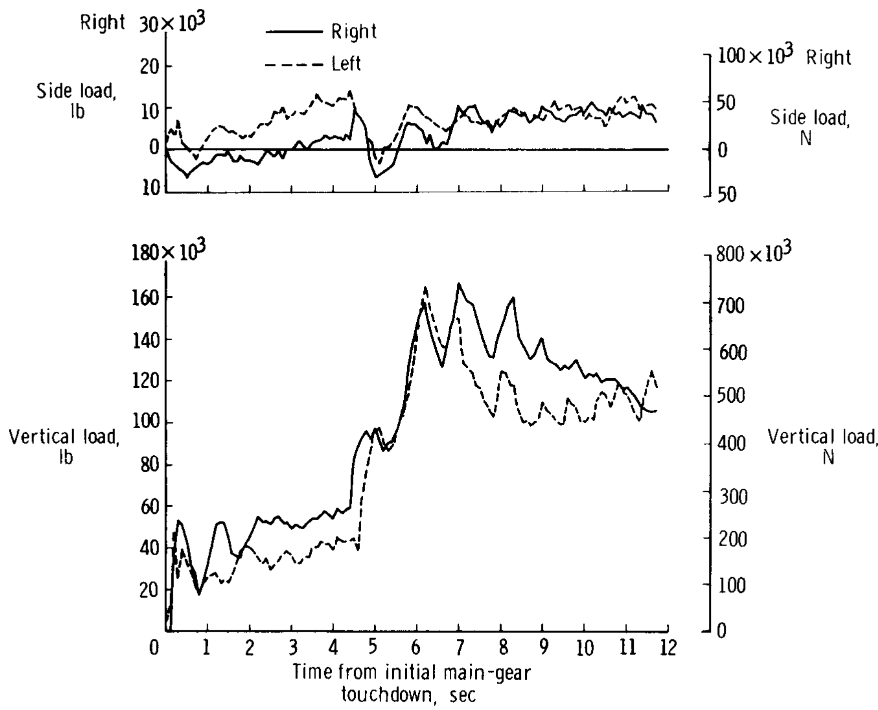


(a) Airplane attitude.

Figure 9.— Typical time histories of angles of attack, roll, and sideslip, landing-gear loads, and accelerations. XB-70-1 flight 13.



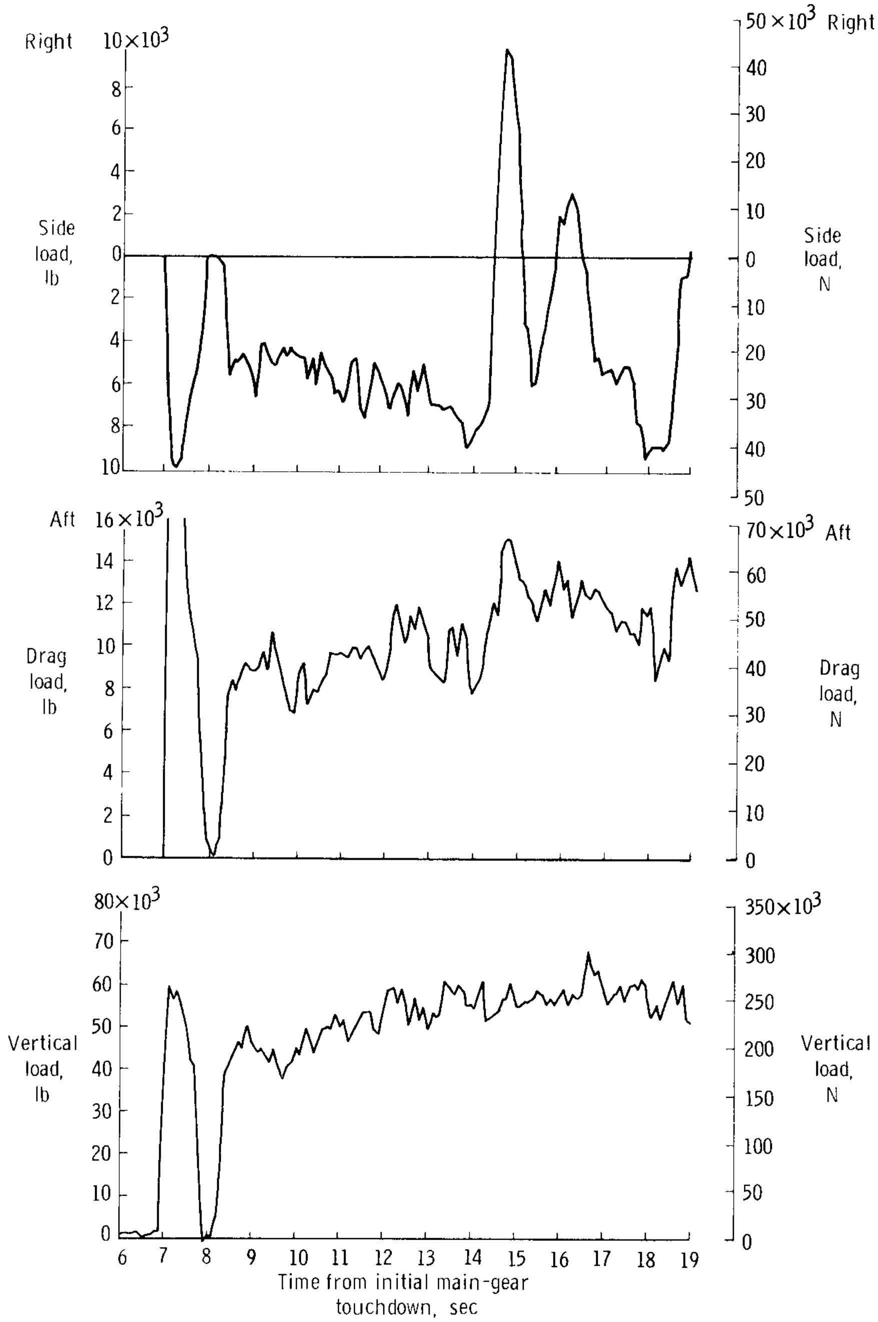
(b) Forward and aft right main-gear truck loads.



(c) Total main-gear loads.

Figure 9.— Continued.

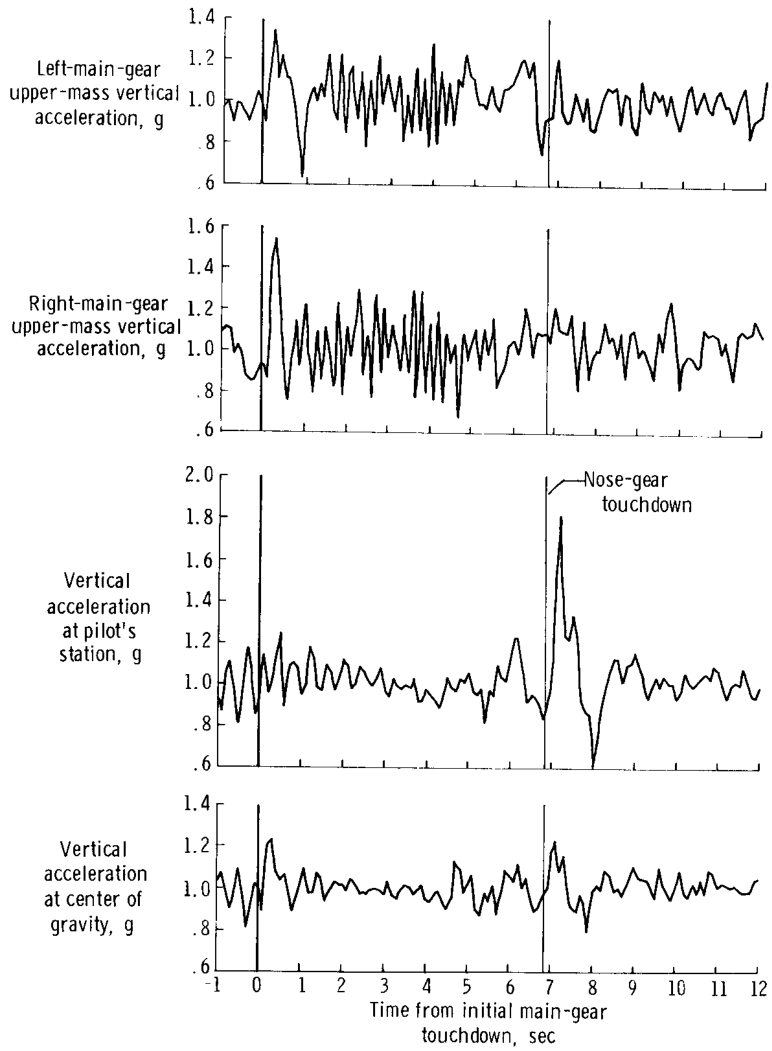
The nose-gear loads (fig. 9(d)) show nose-gear contact 6.9 seconds after main-gear touchdown. A vertical load of 59,610 pounds (265,158 newtons) was initially experienced during the contact and spin-up. The initial load was almost as great as the maximum load of 68,860 pounds (306,304 newtons). The drag-load instrumentation operated intermittently at contact; some side loads were also erratic.



(d) Nose-gear loads.

Figure 9.— Continued.

The vertical accelerations are presented in figure 9(e). Peak accelerations at main-gear contact at the center of gravity and the pilot's station were 1.23g and 1.26g, respectively. At nose-gear contact these values reached 1.23g and 1.81g, respectively. The value of 1.81g at the pilot's station was the third highest value recorded in this study.



(e) Airplane and main-gear upper-mass accelerations.

Figure 9.— Concluded.

The variation of maximum vertical force on the main gear with vertical velocity is presented in figure 10. Data from actual landings were divided into three ranges of landing weight: 280,000 pounds (127,000 kilograms) to 310,000 pounds (140,600 kilograms); 310,000 (140,600 kilograms) to 370,000 pounds (167,800 kilograms); and 370,000 pounds (167,800 kilograms) and greater. These data are compared with theoretical landing loads computed for a 370,000-pound (167,800-kilogram) and 542,000-pound (245,800-kilogram) aircraft.

The method used to analyze the theoretical loads is presented in references 4 and 5. Briefly, the modal superposition method was used to calculate the

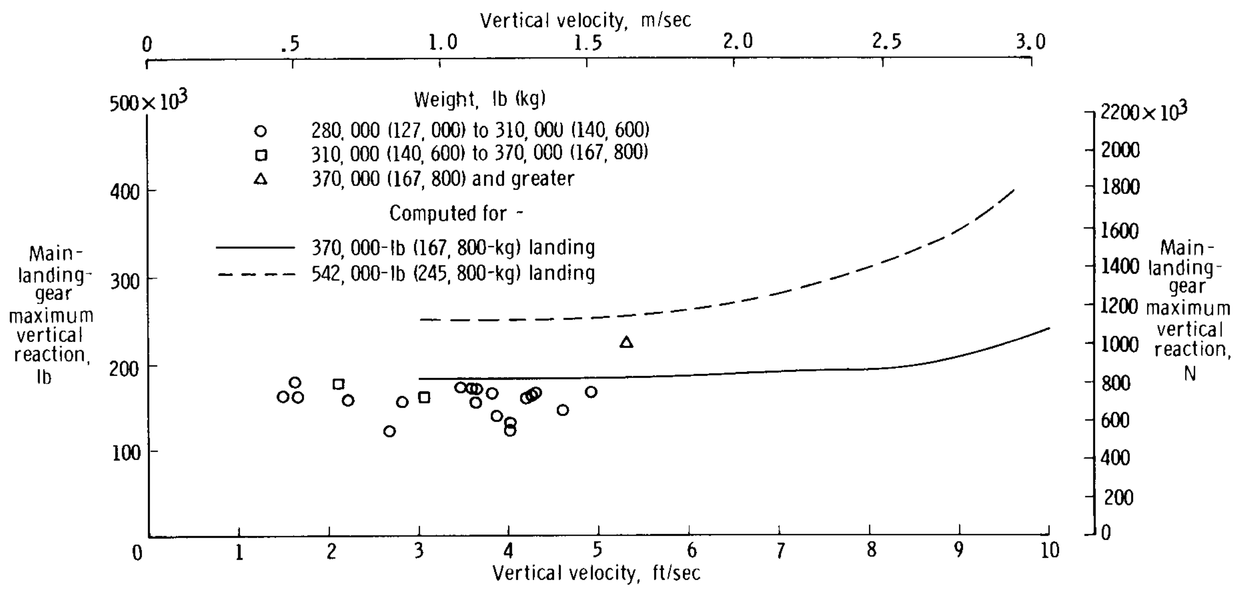


Figure 10.— Variation of main-gear maximum vertical reaction with main-gear vertical velocity.

dynamic-elastic-response loads. The first four airplane structural modes were used in addition to the degrees of freedom of airplane plunge, airplane pitch, forward speed of unsprung masses, plunge of unsprung masses, wheel rotations, and bogie rotation. The landing-gear equations included the polytropic gas compression, velocity-squared hydraulic damping, bearing sliding and breakout friction, and the nonlinear dynamic tire force characteristics.

As illustrated in figure 10, the actual landing loads agreed well with the computed loads. Most of the landing weights were within the 280,000-pound (127,000-kilogram) to 310,000-pound (140,600-kilogram) range. Two landing weights were between 310,000 pounds (140,600 kilograms) to 370,000 pounds (167,800 kilograms), and one landing weight was greater than 370,000 pounds (167,800 kilograms). Differences between the computed loads and the measured loads may be caused by the variations between the idealized conditions and the actual landing techniques used by the pilots. The narrow band of vertical-velocity data is attributed to the fact that no special requirements were set for landing conditions and none of the flights were flown specifically to obtain landing-loads data.

The variation of the initial maximum vertical load on the nose gear with main-gear vertical velocity is presented in figure 11. As in figure 10, data from actual landings were divided into the three ranges of landing weight noted previously and compared with theoretical loads computed for a 370,000-pound (167,800-kilogram) and a 542,000-pound (245,800-kilogram) aircraft. Most of the measured data are below the predicted loads. This variation may be attributed to the greater time interval between main-gear and nose-gear touchdown for the observed landings (average 8.6 seconds, table III) as compared to times used for the analysis

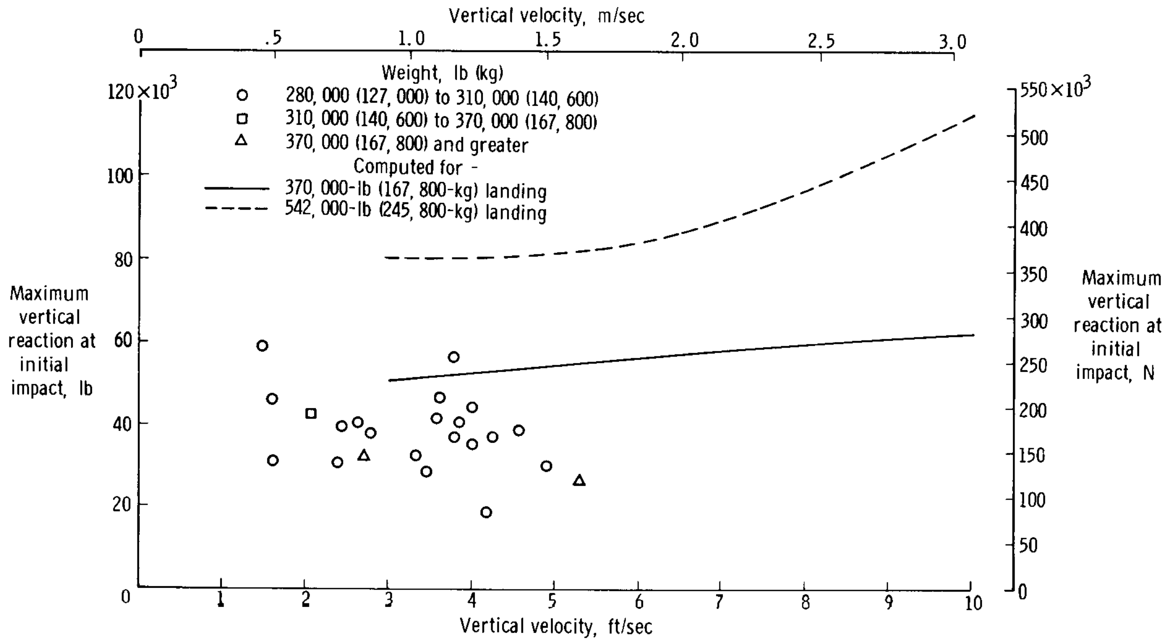


Figure 11.– Variation of nose-gear vertical reaction with main-gear vertical velocity.

(approximately 5 seconds). This would indicate that the pilot has adequate control available to maintain a low nose-gear vertical velocity after main-gear touchdown, thereby resulting in reduced nose-gear vertical loads.

Measured data are compared with analytical predictions in figure 12 for peak normal accelerations at the airplane center of gravity and the pilot's station with vertical velocity at main-gear touchdown. The maximum accelerations experienced at the center of gravity and the pilot's station due to main-gear impact were 1.57g and 1.99g, respectively, with a mean of 1.37g and 1.39g. A greater acceleration (1.97g) was experienced at the center of gravity in flight 43; however, vertical velocity could not be determined for the landing so the value is not shown in figure 12.

These data show that the response at the pilot's station was slightly greater than that at the center of gravity. The accelerations measured at the pilot's station fell below the predicted values. This variation may be attributed to the difference between the actual and the anticipated stiffness factors and associated natural frequencies of the fuselage. The pilots' observations at main-gear impact on flights 7 and 9 indicated that they had difficulty in determining when the airplane was down. The peak normal accelerations for these landings at the center of gravity and the pilot's station were, respectively, 1.17g and 1.47g for flight 7 and 1.40g and 1.65g for flight 9.

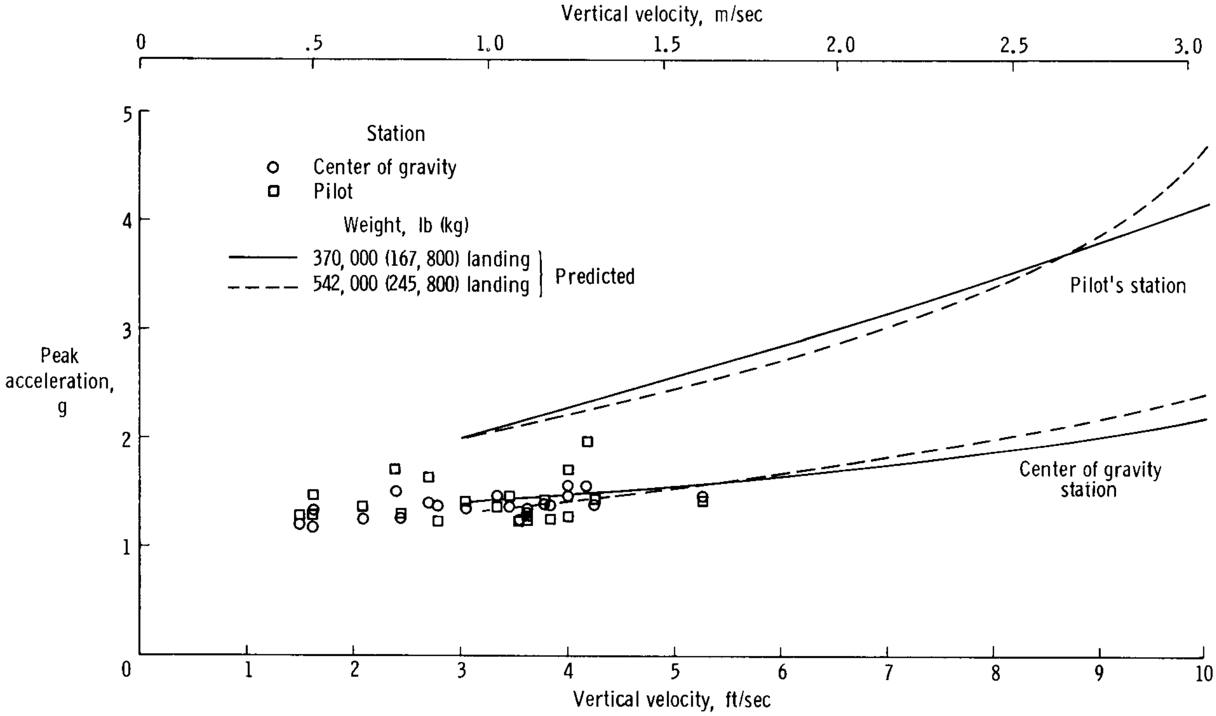


Figure 12.– Variation of peak acceleration with vertical velocity at main-gear touchdown.

The peak vertical accelerations at the center of gravity and the pilot's station as a function of nose-gear vertical velocity are presented in figure 13. The maximum

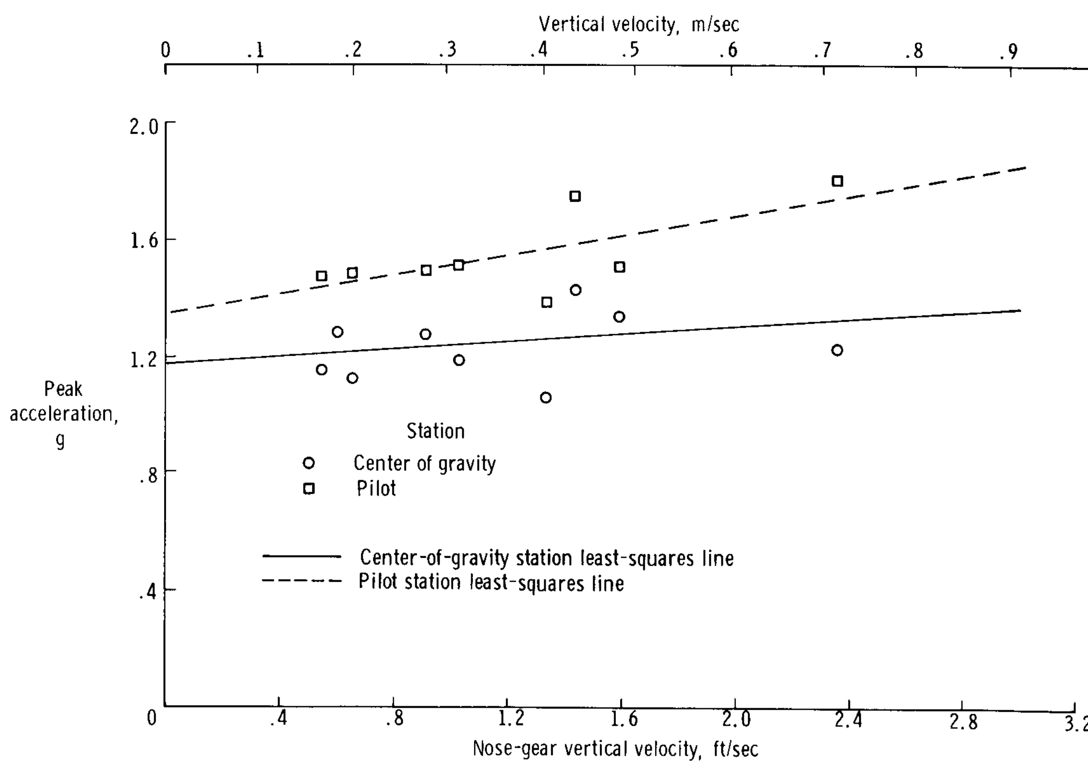


Figure 13.– Variation of peak acceleration with vertical velocity at nose-gear touchdown.

accelerations at the center of gravity and the pilot's station due to nose-gear impact were 1.43g and 1.81g, respectively; the mean accelerations were 1.23g and 1.54g. The maximum values of vertical acceleration at the center of gravity and the pilot's station in table III were 1.45g and 1.88g, respectively. Since values of nose-gear vertical velocity were not available for all landings, these values were not included in figure 13. Again, the data of figure 13 show the response at the pilot's station to be somewhat greater than at the center of gravity and to be slightly higher than the responses recorded for main-gear impact. The highest recorded nose-gear vertical velocity was 2.35 feet/second (0.716 meter/second) on flight 13. Vertical velocities on other touchdowns ranged from 0.54 foot/second (0.165 meter/second) on flight 18 to 1.59 feet/second (0.485 meter/second) on flight 9, with a mean value of 1.12 feet/second (0.341 meter/second).

Presented in figure 14 is the variation of incremental acceleration with vertical velocity experienced at the airplane center of gravity during main-gear touchdown. A least-squares line, forced through zero, was fitted to the data to illustrate expected trends of acceleration with increased vertical velocity.

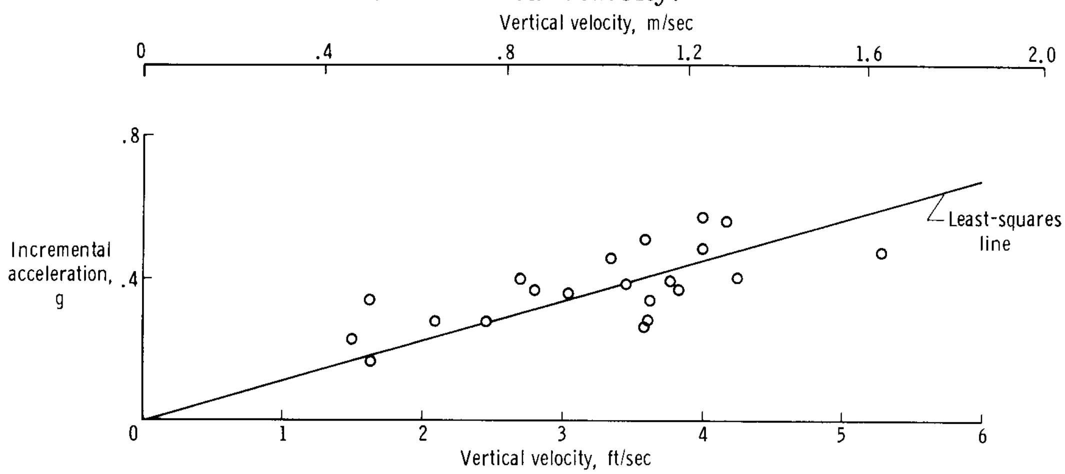


Figure 14.– Variation of incremental acceleration at the airplane center of gravity with vertical velocity at main-gear touchdown.

CONCLUDING REMARKS

Data were obtained from the first 48 landings of the XB-70-1 airplane on landing-contact condition, landing loads, and the response of the airplane to landing impact. A comparison of the landing-contact conditions of the XB-70-1 and a modern turbojet transport showed that the mean indicated airspeed for the XB-70-1 of 180.5 knots was 47.7 knots greater than for the turbojet transport. The mean vertical velocity at touchdown for the XB-70-1, 3.21 feet/second (0.978 meter/second), was 1.59 feet/second (0.484 meter/second) higher than for the transport. The maximum XB-70-1 roll angle at touchdown (3.0°) and rolling velocity (3.28 degrees/second) were both lower than the values (4.3° and 8.7 degrees/second) reported for the transport.

The measured XB-70-1 main-gear maximum vertical reactions generally compared favorably with predicted values. The nose-gear initial maximum vertical reactions were generally less than the predicted values. The difference may be attributed to piloting techniques during landing and the control available after touchdown as shown by the average nose-gear touchdown vertical velocity of 1.12 feet/second (0.341 meter/second) and the average time from main-gear to nose-gear touchdown of 8.6 seconds.

The mean acceleration measured at the pilot's station was 1.39g due to main-gear impact and 1.54g due to nose-gear impact. The mean accelerations experienced at the center of gravity due to main-gear and nose-gear impact were 1.37g and 1.23g, respectively.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., September 22, 1967,
732-01-00-03-24.

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TABLE I. - XB-70-1 INSTRUMENTATION

Parameter	Pickup		Recording system frequency, cps		Accuracy, percent full range	Location		
	Type*	Range	Digital	Analog		Fuselage station, in.	Butt plane, in.	Water plane, in.
Nose-boom angle of attack	A	-10° to 30°	4.0	--	0.8	92	6	20
Pitch at center of gravity	B	-10° to 40°	4.0	--	2.0	1415	16	-64
Roll at center of gravity	B	$\pm 45^{\circ}$	4.0	--	2.0	1415	16	-64
Nose-boom angle of sideslip	A	$\pm 20^{\circ}$	4.0	25	0.8	121	0	13
Pitch rate at center of gravity	C	± 10 deg/sec	4.0	--	2.0	1404	16	-64
Roll rate at center of gravity	C	± 100 deg/sec	4.0	--	2.0	1404	16	-64
Airspeed (coarse)	D	50 to 800 knots	0.8	--	2.0	80	0	14
Airspeed (fine)	D	70 knots/revolution	0.8	--	2.0	80	0	14
Normal acceleration at center of gravity	E	$\pm 2g$	4.0	30	2.0	1485	11	-71
Normal acceleration at pilot's station	E	$\pm 5g$	4.0	--	2.0	438	12	36
Upper-strut vertical acceleration, left main gear	E	$\pm 5g$	20.0	--	2.0	1695.5	-148	-124
Upper-strut vertical acceleration, right main gear	E	$\pm 5g$	20.0	--	2.0	1695.5	148	-124
Left-main-gear stroke	F	0 to 14 in. (0 to 0.356 m)	20.0	--	2.0	------	----	----
Right-main-gear stroke	F	0 to 14 in. (0 to 0.356 m)	20.0	--	2.0	------	----	----
Nose-gear stroke	F	0 to 14 in. (0 to 0.356 m)	20.0	--	2.0	------	----	----
Wheel rpm, left forward	G	0 to 2,000	12.0	--	1.0	------	----	----
Wheel rpm, left aft	G	0 to 2,000	12.0	--	1.0	------	----	----
Wheel rpm, right forward	G	0 to 2,000	12.0	--	1.0	------	----	----
Wheel rpm, right aft	G	0 to 2,000	12.0	--	1.0	------	----	----
Trailing arm, left main gear	F	0 to 12 in. (0 to 0.305 m)	----	35	2.5	------	----	----
Trailing arm, right main gear	F	0 to 12 in. (0 to 0.305 m)	----	35	2.5	------	----	----
Trailing arm, nose gear	F	0 to 12 in. (0 to 0.305 m)	----	35	2.5	------	----	----
Main-gear and nose-gear strain gage	H	-----------------	20.0	--	2.0	------	----	----

*A Attack and sideslip sensor - linear variable differential transformer.
B Attitude gyro - 2K potentiometer pickoff.
C Rate gyro - microsyn pickoff.
D 2K potentiometer pickoff.
E Accelerometers - strain gage.
F Position transmitter - strain gage bend beam.
G A/V electrical system - voltage, current and frequency monitoring.
H Bonded strain gage - 350 ohm bridge.

TABLE II. – XB-70-1 LANDING-CONTACT CONDITIONS

Flight*	Landing weight, lb	Landing weight, kg	Indicated velocity at touchdown, knots	Vertical velocity of aft truck at touchdown, Left, ft/sec	Left, m/sec	Right, ft/sec	Right, m/sec	Indicated angle of attack, deg	Angle of roll, deg	Angle of sideslip, deg	Roll rate, deg/sec	Pitch rate, deg/sec
1	307.300	139.400	186.0	Rate of sink arm not installed				9.7	----	1.4	1.24	0.05
2	342.000	155.100	192.2					7.7	0.2	-.2	3.51	-.18
3	308.500	139.900	173.4					9.0	-.8	1.0	6.23	-1.32
4	301.400	136.700	167.3					---	----	---	----	-----
5	295.200	133.900	179.5	----	-----	4.17	1.271	8.8	1.2	.2	3.22	-.24
7	302.300	137.100	182.1	1.01	0.308	1.61	.491	8.3	1.6	.9	.47	-.22
9	419.800	190.400	195.0	1.82	.555	2.70	.823	10.4	.2	.4	-.47	.39
10	299.800	136,000	167.6	3.62	1.103	3.39	1.033	10.2	-1.9	.1	2.15	.27
11	300.100	136.100	175.2	4.00	1.219	3.34	1.018	9.8	2.4	2.0	-1.45	.52
13	300.200	136.200	179.1	1.49	.454	----	-----	9.4	-1.6	2.7	-.24	-----
14	288.900	131.000	180.0	3.23	.984	3.77	1.149	8.4	2.0	1.7	-----	.92
16	289.800	131.500	174.7	----	-----	3.61	1.100	9.0	.7	.1	-.11	.35
17	305.300	138,500	191.7	2.56	.780	2.44	.744	8.8	0	0	-.53	-----
18	292,500	132.700	183.4	3.34	1.018	2.38	.725	8.6	.5	1.2	-1.33	-.10
19	288,600	130.900	182.2	2.66	.811	4.00	1.219	9.1	0	-.1	2.48	.08
20	291.500	132.200	182.5	3.57	1.088	3.57	1.088	8.6	-.4	-.1	.48	.35
21	299,000	135.600	190.0	1.61	.491	2.22	.677	8.6	.1	0	-.44	-.74
22	291,700	132.300	-----	4.16	1.268	4.55	1.387	---	----	---	-----	-----
23	295.000	133,800	173.9	3.45	1.051	3.33	1.015	9.8	-.1	.1	-.54	.22
24	289.400	131.300	179.5	3.84	1.170	2.94	.896	8.7	-.8	-.5	-.73	-.03
25	291.300	132.100	175.7	2.44	.744	2.78	.847	8.7	.6	-1.2	-.34	-.69
26	323.400	146.700	190.4	2.70	.823	3.03	.924	9.4	-2.1	-.8	-.99	-.82
27	286.800	130.100	-----	2.86	.872	2.40	.731	---	----	---	-----	-----
28	289.400	131.300	180.0	4.25	1.295	4.16	1.268	8.8	0	-.1	-.17	.09
29	314.900	142.800	180.0	2.08	.634	3.57	1.088	10.0	-2.2	1.6	-.36	.01
30	287.800	130.500	-----	2.15	.655	2.63	.802	---	----	---	-----	-----
31	286.800	130.100	-----	4.55	1.387	4.88	1.487	---	----	---	-----	-----
32	374.500	169.900	193.4	5.26	1.603	3.33	1.015	10.6	-.5	1.0	-.48	.51
33	286.800	130.100	180.4	3.57	1.088	2.38	.725	8.8	-1.1	.5	0	-.16
34	323.000	146.500	-----	4.55	1.387	4.55	1.387	---	----	---	-----	-----
37	274.600	124.600	-----	Rate of sink arm not installed				---	----	---	-----	-----
38	323.500	146.700	-----					---	-2.0	---	-3.28	-.46
39	286.400	129.900	185.5					9.3	-2.0	-.2	-.13	.19
40	281.700	127.800	173.6					9.7	-.4	-.8	-.66	-.60
41	278.300	126.200	175.3					8.9	2.0	.6	-1.64	0
42	289.000	131.100	174.9					9.4	-.5	1.1	-.36	-.75
43	288.200	130.700	176.2					9.4	.6	.2	-2.36	.40
44	287.600	130.500	182.3					7.4	3.0	.3	-1.88	-.15
45	287.300	130.300	179.2					10.2	0	.6	.41	-.38
46	282.600	128.200	184.0					8.5	-2.0	.4	-.72	.21
47	296.800	134.600	172.1					9.5	-.3	.8	1.82	.17
48	333.900	151,400	178.7					10.3	-.2	.8	-.63	-.94

Dashes indicate unusable data.
*Flights 6, 8, 12, 15, 35, and 36 excluded due to insufficient data.

TABLE III. – XB-70-1 LANDING IMPACT CONDITIONS

Flight*	Landing weight,		Vertical velocity of aft truck at touchdown,				Time of main-landing-gear impact, aft truck, sec		Time of nose-gear impact, sec	Nose-gear vertical velocity,		Main-landing-gear maximum vertical load, (for one gear only)		Nose-gear maximum vertical load,		Peak vertical acceleration, main-gear impact, g		Peak acceleration, nose-gear impact, g		Spin-up nose-gear vertical load,	
			Left		Right																
	lb	kg	ft/sec	m/sec	ft/sec	m/sec	Left	Right		ft/sec	m/sec	lb	N	lb	N	Center of gravity	Pilot	Center of gravity	Pilot	lb	N
1	307,300	139,400	Rate of sink arm not installed				---	0	7.2	Rate of sink arm not installed		154,000	685,026	74,570	331,704	1.44	1.68	1.35	1.66	36,770	163,561
2	342,000	155,100					---	0	7.93			173,700	772,656	70,000	311,375	1.37	1.42	1.06	1.49	33,000	146,791
3	308,500	139,900					---	0	7.1			159,800	710,826	90,380	402,030	1.24	1.42	1.27	1.88	42,700	189,938
4	301,400	136,700					---	0	7.0			176,100	783,332	54,900	244,207	----	----	----	----	54,600	242,872
5	295,200	133,900	----	-----	4.17	1.271	0	.01	12.3	0.91	0.277	163,000	725,060	76,140	338,687	1.56	1.99	1.28	1.50	19,520	86,829
7	302,300	137,100	1.01	0.308	1.61	.491	.27	0	17.02	.60	.183	178,500	794,007	82,670	367,734	1.17	1.47	1.28	----	31,150	138,562
9	419,800	190,400	1.82	.555	2.70	.823	0	0	7.5	1.59	.485	-------	---------	121,000	538,235	1.40	1.65	1.34	1.51	31,100	138,339
10	299,800	136,000	3.62	1.103	3.39	1.033	0	.2	10.5	.65	.198	174,900	777,994	77,210	343,447	1.34	1.32	1.12	1.49	31,200	138,784
11	300,100	136,100	4.00	1.219	3.34	1.018	0	0	5.4	----	-----	124,300	552,914	81,740	363,598	1.48	1.72	1.38	1.49	35,140	156,310
13	300,200	136,200	1.49	.454	----	-----	.03	0	6.9	2.35	.716	165,700	737,070	68,860	306,304	1.23	1.26	1.23	1.81	59,610	265,158
14	288,900	131,000	3.23	.984	3.77	1.149	.20	0	14.6	.75	.229	168,800	750,860	62,760	279,170	1.39	1.42	----	----	56,560	251,591
16	289,800	131,500	----	-----	3.61	1.100	.10	0	6.6	1.43	.436	157,000	698,370	63,240	281,305	1.28	1.27	1.43	1.75	46,730	207,865
17	305,300	138,500	2.56	.780	2.44	.744	.10	0	7.9	1.33	.405	-------	---------	61,930	275,478	1.28	1.26	1.06	1.39	39,580	176,060
18	292,500	132,700	3.34	1.018	2.38	.725	0	0	7.8	.54	.165	-------	---------	74,330	330,636	1.46	1.37	1.15	1.48	32,060	142,609
19	288,600	130,900	2.66	.811	4.00	1.219	.20	0	5.1	1.02	.311	133,400	593,392	72,600	322,941	1.57	1.28	1.19	1.51	43,300	192,607
20	291,500	132,200	3.57	1.088	3.57	1.088	0	0	8.8	Rate of sink arm not installed		170,500	758,421	60,550	269,340	1.26	1.24	1.35	1.87	41,560	184,868
21	299,000	135,600	1.61	.491	2.22	.677	0	.1	3.9			164,000	729,508	64,270	285,887	1.34	1.30	1.16	1.64	46,340	206,130
22	291,700	132,300	4.16	1.268	4.55	1.387	---	---	-----			147,200	654,778	75,380	335,307	----	----	----	----	38,650	171,923
23	295,000	133,800	3.45	1.051	3.33	1.015	0	0	6.6			174,400	775,770	52,310	232,686	1.38	1.46	1.21	1.56	28,720	127,752
24	289,400	131,300	3.84	1.170	2.94	.896	0	.1	-----			142,800	635,206	52,650	234,199	1.37	1.26	----	----	40,870	181,798
25	291,300	132,100	2.44	.744	2.78	.847	.3	0	13.1			157,700	701,484	61,490	273,521	1.37	1.23	1.25	1.51	37,500	166,808
26	323,400	146,700	2.70	.823	3.03	.924	.1	0	-----			163,500	727,284	-------	-------	1.36	1.41	----	----	------	-------
27	286,800	130,100	2.86	.872	2.40	.731	---	---	-----			-------	---------	-------	-------	----	----	----	----	------	-------
28	289,400	131,300	4.25	1.295	4.16	1.268	0	0	6.7			165,300	735,291	44,370	197,368	1.40	1.43	1.25	1.52	37,670	167,564
29	314,900	142,800	2.08	.634	3.57	1.088	0	.1	9.0			179,000	796,231	98,400	437,705	1.28	1.37	1.12	1.36	42,050	187,047
30	287,800	130,500	2.15	.655	2.63	.802	---	---	-----			124,300	552,914	71,000	315,824	----	----	----	----	40,370	179,574
31	286,800	130,100	4.55	1.387	4.88	1.487	---	---	-----			166,200	739,294	49,900	221,966	----	----	----	----	30,400	135,225
32	374,500	169,900	5.26	1.603	3.33	1.015	0	.1	11.2			225,000	1,000,849	87,320	388,419	1.47	1.45	1.11	1.28	26,830	119,345
33	286,800	130,100	3.57	1.088	2.38	.725	.4	0	8.3			159,600	709,936	36,460	162,182	1.51	1.71	1.21	1.53	30,620	136,204
34	323,000	146,500	4.55	1.387	4.55	1.387	---	---	-----			-------	---------	-------	-------	----	----	----	----	------	-------
37	274,600	124,600	Rate of sink arm not installed				---	---	-----			149,700	665,898	61,990	275,745	----	----	----	----	51,170	227,615
38	323,500	146,700					0	.4	9.1			167,300	744,187	118,500	527,114	1.31	1.33	1.25	1.36	42,000	186,825
39	286,400	129,900					0	.4	-----			162,900	724,615	87,850	390,776	----	----	----	----	62,410	277,613
40	281,700	127,800					0	.2	4.3			164,400	731,287	60,460	268,939	1.29	1.32	1.22	1.55	38,140	169,655
41	278,300	126,200					0	0	-----			149,700	665,898	68,630	305,281	1.50	1.62	1.45	1.54	41,950	186,602
42	289,000	131,100					0	.2	12.1			167,500	745,077	52,650	234,199	1.18	1.27	1.20	1.45	25,740	114,497
43	288,200	130,700					0	.05	-----			144,800	644,102	72,100	320,717	1.97	1.34	1.20	1.61	71,300	317,158
44	287,600	130,500					---	---	5.6			126,800	564,034	64,990	289,090	1.20	1.29	1.36	1.61	57,080	253,904
45	287,300	130,300					---	---	5.6			181,500	807,352	72,220	321,250	1.28	1.36	1.13	1.43	59,850	266,225
46	282,600	128,200					---	---	17.1			151,700	674,795	56,390	250,835	1.26	1.10	1.13	1.28	39,370	175,126
47	296,800	134,600					---	---	5.8			160,600	714,384	75,230	334,639	1.33	1.20	1.18	1.56	46,970	208,932
48	333,900	151,400					---	---	8.8			210,400	935,905	66,480	295,718	1.18	1.20	1.16	1.54	48,600	216,183

Dashes indicate unusable data.
*Flights 6, 8, 12, 15, 35, and 36 excluded because of insufficient data.